INTRODUCTION

Severe and prolonged droughts between 1961 and 1988, combined with increased demands for freshwater supplies in the United States, have resulted in a critical need to assess the potential for development of ground- and surface-water supplies. Rapid industrial growth and urban expansion have caused existing freshwater supplies to be used at or near maximum capacity. Begun in 1978, the Regional Aquifer-System Analysis (RASA) Program of the U.S. Geological Survey (USGS) is a systematic effort to study a number of the Nation's most important aquifer systems, which, in aggregate, underlie much of the country and represent an important component of the Nation's total water supply. The broad objective for each of the 28 studies in the program is to assemble geologic, hydrologic, and geochemical information, to analyze and develop an understanding of the system, and to develop predictive capabilities that will contribute to the effective management of the system.

In 1988, as part of the RASA Program, the USGS began a 6-year study of the ground-water resources of parts of 11 States in the Eastern United States (Swain and others, 1991). The study was designated the Appalachian Valley and Piedmont Regional Aquifer-System Analysis (APRASA). The APRASA team investigated ground-water resources primarily in the unglaciated part of the Valley and Ridge, the Blue Ridge, the New England, and the Piedmont Physiographic Provinces (fig. 1). For the purposes of this report, the small area in the New England Physiographic Province that is within the study area in New Jersey and Pennsylvania was considered part of the Piedmont Physiographic Province. The results of the APRASA are contained in about 50 reports and abstracts, including reports on simulation of ground-water flow in three type areas, this atlas, and chapters in Professional Paper 1422. These chapters include the summary (Chapter A), descriptions of recharge rates and surface- and ground-water relations (Chapter B), hydrogeologic terranes in the Valley and Ridge Physiographic Province (Chapter C), and ground-water geochemistry (Chapter D).

The purposes of this atlas are to summarize the hydrogeology, to describe an analysis of maps and well records, and to present a classification and map of the hydrogeologic terranes of the Blue Ridge and Piedmont Physiographic Provinces within the APRASA study area. Hydrogeologic terranes are defined for this atlas as regionally mappable areas characterized by similar water-yielding properties of a grouping of selected rock types. The hydrogeologic terranes represent areas of distinct hydrologic character. The terranes are intended to help water users locate and develop adequate water supplies and to help hydrologists interpret the regional hydrogeology.

Previous investigations provide maps and descriptions of the geologic units, describe the local quantity and quality of ground water within these units, and establish the statistical methods for comparing the water-yielding properties of these units. State geologic maps show the distribution of geologic units at a scale of 1:500,000 for Alabama (Osborne and others, 1989), Georgia (Lawton and others, 1976), North Carolina (Brown and Parker, 1985), and Virginia (Calver and Hobbs, 1963). State maps show geologic units at a scale of 1:250,000 for Maryland (Cleaves and others, 1968), New Jersey (Lewis and Kummel, 1912), Pennsylvania (Berg and others, 1980), South Carolina (Overstreet and Bell, 1965), Tennessee (Hardeman, 1966), and West Virginia (Cardwell and others, 1968). Quadrangle geologic maps show geologic units at a scale of 1:24,000 for parts of Delaware within the APRASA area (Woodruff and Thompson, 1972, 1975). Many reports have been published describing the groundwater resources of a county, parts of a county, multi-county areas, or river basins.

The statistical methods used in this atlas are based largely on those used by Helsel and Hirsch (1992) and by Knopman (1990, p. 7-9). In her analysis of well records in the USGS Ground-Water Site Inventory (GWSI) data base, Knopman (1990) ranked factors that must be taken into account when assessing the water-yielding potential of the rocks in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces in Pennsylvania. Readers are referred to Helsel and Hirsch (1992) and Knopman (1990) for details regarding statistical methods.

HYDROGEOLOGIC SETTING

The Blue Ridge and Piedmont Physiographic Provinces are underlain by metamorphic, igneous, and sedimentary rocks, many of which have undergone several periods of metamorphism and intrusive activity. Although 35 rock types have been identified and mapped in the Blue Ridge and 53 in the Piedmont, four rock types—gneiss, schist, granite, and phyllite—underlie more than 64 percent of each province. The bedding and foliation are usually folded and tilted, can exhibit variable orientations, and 10 gal/min of water. Data from nondomestic wells (primarily industrial, public, and irrigation supplies) commonly intersect one another in systematic geometric patterns. Although most rocks have strong were used to statistically classify and to delineate hydrogeologic terranes even though a smaller directional fabric, igneous intrusives emplaced after the last metamorphic event in the late Paleozoic amount of data was available as compared with data available for both nondomestic and domestic Era tend to be massive and less foliated. The rocks were subjected to uplift during the Cenozoic Era, and subsequent weathering and erosion opened or widened existing fractures or created new ones by for yield and could be associated with a rock type; about one-quarter—3,864 wells—had values for stress relief. Fault zones of differing types, scales, and orientations are common; some fault zones are specific capacity and could be associated with a rock type. Data from the GWSI data base were merged characterized by an abundance of fractures.

Regolith (soil, sediment, weathered rock) covers the consolidated rock throughout the study area, and bedrock typically is exposed only in areas of rugged topography or in stream channels where erosion has removed the surficial materials. The regolith either was formed in place by the weathering of the underlying bedrock (residuum) or was deposited after being transported from the place of weathering (till, colluvium, alluvium). Much of the regolith in the study area is fine-grained residuum that retains the structural features of the parent bedrock (saprolite). Residuum commonly is thin (less than 5 ft) on shale, phyllite, and carbonate rock, but can be thick (more than 50 ft) on rock that contains substantial amounts of resistant quartz, quartzite, or well-cemented quartz sandstone. Glacial till with a sandy or clayey matrix covers much of the uplands in New Jersey and eastern Pennsylvania and is commonly less than 3 ft thick. In major valleys in the same area, alluvium commonly is more than 30 ft thick and is coarse-grained, well sorted, and derived directly or indirectly from glacial deposits. Although of small areal extent in comparison to the entire study area, this alluvium produces some of the largest yields of water to wells of any geologic unit in the study area. Within and adjacent to the Blue Ridge Physiographic Province, thin, stony colluvium overlies residuum or bedrock on hill and mountain slopes that are crested by resistant siliciclastic rock. The colluvium commonly grades downslope into disected alluvial terraces containing cobble gravel, sand, and sandy loam. In several places (Frederick Valley, Mountain City-Shady Valley, for examples), colluvial-alluvial aprons cover cavernous, carbonate rock, which discharges to large springs and maintains unusually large base flow during dry weather (Hollyday and others, 1997).

The water-storage and transmission characteristics of the bedrock and the regolith and the hydraulic connection between the bedrock and the regolith determine the water-supply potential of the aquifers in the metamorphic and igneous rocks in the two provinces (fig. 2). Wells that penetrate consolidated rocks in areas mantled by thick, saturated regolith generally have higher sustained yields than wells where regolith is thin or absent. Porosity of the regolith is about 35 to 55 percent near land surface (Stewart, 1962) but decreases with depth as the degree of weathering decreases. Porosity of the underlying bedrock is only 0.01 to 2 percent (Heath, 1984). Because of the relatively large porosity of the regolith, recharge is stored primarily in the regolith and is released slowly to underlying bedrock fractures. The transition zone between the saprolite and the unweathered bedrock is often more permeable than the saprolite. If the transition zone is sufficiently thick, significant amounts of ground water can flow laterally in this zone. Laboratory analyses of samples of saprolite in Maryland and Georgia indicate a wide range of hydraulic conductivity -0.0013 to 15 ft/d (Nutter and Otton, 1969). The abundance of connected fractures in the bedrock directly affects the yield of wells in these rocks. Because fractures act as conduits for ground-water flow, well yields are greatest where wells intersect fractures that are large, numerous, or both. Because the number and size of fractures decrease with depth in the Blue Ridge and Piedmont rocks, few wells in these two provinces are drilled more than

Several basins and valleys that are filled with sedimentary rocks lie within the expanse of wells from conduits dissolved in the dense rock.

Siliciclastic and volcanic rocks fill a series of 15 elongated, down-faulted basins that lie within the Piedmont Physiographic Province in a discontinuous belt extending almost 600 mi from New York into South Carolina. These basins were formed in Triassic and early Jurassic time during the incipient rifting of the continent. Concurrently, they were filled with thick (up to 20,000 ft) sequences of siltstone, red shale, sandstone, and conglomerate that were intruded later by diabase sills and dikes. Structurally, most geologic units strike northeast and dip between 5 and 40 degrees toward the main border faults, commonly on the northwest or southeast margins of the basins. Ground water in the siliciclastic rocks is stored and transmitted primarily through a complex network of interconnected openings formed along bedding-plane partings, joints, and faults. To a lesser extent, water is stored and moves through interstitial pores. The three Mesozoic basins (fig. 1) near the northeastern end of the discontinuous belt of 15 Mesozoic basins contain fractured shale, siltstone, and sandstone which yield as much as 2,200 gal/min to individual wells. Regionally, well yields tend to decrease substantially from north to to 85 percent. south along the belt of 15 basins; this decrease is accompanied by a decrease from north to south in overall grain size of the sediments that were deposited in the basins. Within the Mesozoic basins, wateryielding openings generally decrease in number and width of opening as depth below land surface

Because fractures tend to decrease in number and size with depth, investigators have assumed that well yields decrease with depth. Data from a combination of domestic and nondomestic wells were sufficient in seven local areas in the Piedmont Physiographic Province to investigate the relation between well yield and total depth of well as part of the APRASA study. The method was to compute the average yield of wells grouped according to their total depth into classes covering 50-ft-depth intervals and to plot the average yield against the average depth of the interval (fig. 3). The curves for Howard and Montgomery Counties, Md., Greenville-Spartanburg, S.C., and counties west of Atlanta, Ga., show neither increase nor decrease in average yield with increase in average depth. On the other hand, the curves for counties around and near Winston-Salem, Statesville, and Charlotte, N.C., show a substantial increase in average yield with increase in average depth to depths of 400 or 600 ft, followed by a decrease in average yield with increase in average depth. The curve for counties around and near Atlanta, Ga., shows an abrupt increase in average yield with average depths between 300 and 400 ft,

SELECTION AND ANALYSIS OF RECORDS AND VARIABLES

Hydrogeologic terranes were classified separately within the two physiographic provinces by relating rock type to the yield of nondomestic wells. The hydrogeologic terranes were then mapped by classify and map hydrogeologic terranes involved several choices and methods. These included their water-yielding properties as indicated by the specific capacity of wells. appropriate map scales, map projections, identification of the principal rock type in each geologic unit, and the use of all wells, or simply nondomestic wells, in statistical analysis. The selected choices and methods are described below.

GEOLOGIC MAPS

State geologic maps exist for the entire study area (fig. 1). The State maps, at scales of 1:500,000 and 1:250,000, were selected over maps of smaller or larger scale, or more recent vintage, because they depicted rock type in addition to rock age at a convenient scale. Excepting Delaware, film-positive images of the geologic-contact separates of each of the State maps were scanned and the resulting vector files were converted to line spatial data coverages, which were extensively edited to remove extraneous information and to match coverages for adjacent States (Mesko, 1993). State boundaries were added to each State coverage using a single APRASA-wide scale. All coverages were reprojected from their original coordinate systems into the Albers coordinate system and joined to make a single geologic-unit coverage of the APRASA area. Maps at a scale of 1:24,000 (less than statewide) were used to cover the small area of Delaware within the study area.

A polygon coverage, which represents the area covered by each geologic unit, was created from the geologic-unit line coverage. Each polygon was labeled with the geologic-unit name, map symbol, rock type, and additional attributes. The rock type was determined from the explanation on the published geologic maps. Brief explanations were supplemented with descriptions of geologic units in the lexicons of geologic names. A polygon coverage of rock types was created by merging geologicunit polygons that were labeled with the same rock type. This simplified coverage was then used to identify the rock type associated with each well in the GWSI database.

WELL RECORDS

The complexity of the geology of the Blue Ridge and Piedmont Physiographic Provinces causes large variation in the water-yielding properties of the rocks as compared to the water-yielding properties of sediments in the structurally and lithologically simpler Coastal Plain Physiographic Province. The rock type and to test for significant differences in yield among rock types.

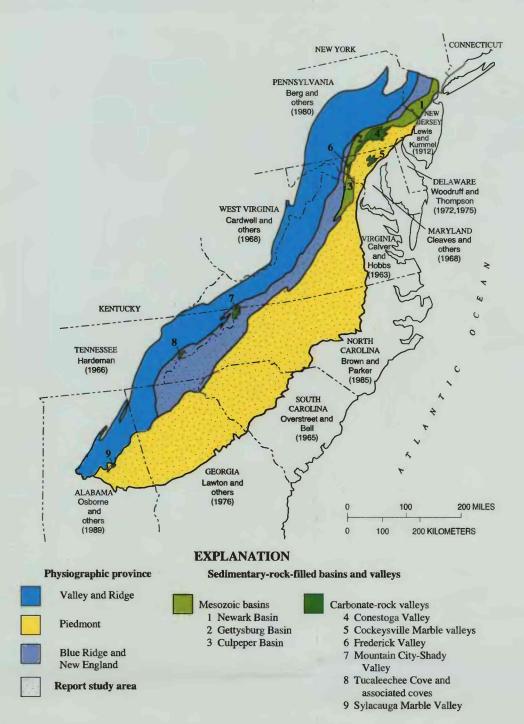


Figure 1. The Appalachian Valley and Piedmont Regional Aquifer-System Analysis study area, physiographic provinces, report study area, sedimentary-rock-filled basins and valleys, and State-geologic-map references.

Records of 40,315 wells in the two provinces in the APRASA study area were retrieved from the GWSI files of the USGS. Among these wells, 93 percent are in the Piedmont Physiographic Province; 70 percent are in Maryland, North Carolina, and Pennsylvania. More than one-half of the wells are used for domestic water supply. Because data from domestic wells usually do not reflect accurately the hydraulic conditions at a well site, these data were not used during the statistical analysis to classify the terranes. The siting, construction, and yield of domestic wells generally are biased because owners are restricted to small areas in which to place a well, often have limited funds, and require only 5 to wells. About half – 8,559 wells – of the records for nondomestic wells in the two provinces had values with the coverage of rock types in order to associate every record of yield and specific capacity with a

HYDROGEOLOGIC TERRANE CLASSIFICATION

Hydrogeologic terranes were classified by relating rock type to the yield of nondomestic wells in the Blue Ridge and Piedmont Physiographic Provinces. Each province was analyzed independently. Well yields for each well were grouped by province and rock type, which had been assigned to the well by merging the well location with the polygon coverage of rock types. The values were analyzed to derive statistical characteristics of yield for each rock type in each province. The rock types were then ranked in order of increasing median yield and grouped into hydrogeologic terranes according to selected ranges in median yield for each province. The medians were then tested for significant differences. If a rock type had fewer than 10 values of well yield, then the sample was considered too small to make an assignment of a rock type to a hydrogeologic terrane. For this reason, although 35 rock types had been mapped in the Blue Ridge, only 12 rock types could be used to classify and map hydrogeologic terranes. Similarly, although 53 rock types had been mapped in the Piedmont, only 26 rock types could be used. Nevertheless, almost the entire study area could be assigned to a lydrogeologic terrane and mapped because the unassigned rock types (amphibolite, mylonite, tonalite, for example) are uncommon and cover small areas relative to the study area.

Previous investigators used similar methods to group rock types into classes according to specific capacity or well yield. Knopman (1990) described factors related to the water-yielding potential of rocks in the APRASA area of Pennsylvania and suggested that there was a statistical basis for grouping geologic units into hydrogeologic units, or terranes, by rock type. Hollyday and Hileman (1996) classified and mapped hydrogeologic terranes in the Valley and Ridge Physiographic Province using statistical analysis of specific-capacity data. Daniel (1989) described a statistical analysis relating well yield to construction and location of wells in the Blue Ridge and Piedmont Physiographic Provinces of North Carolina. Daniel presented well data classified by geologic belts, hydrogeologic units composed of similar rock types, topographic setting, and other parameters. Daniel and Payne (1990) classified rock types into 21 hydrogeologic units in the Blue Ridge and Piedmont Physiographic Provinces of North Carolina on the basis of rock origin, composition, and texture. The units were ranked on the basis

The rock types in each physiographic province were ranked in order of median yield to nondomestic wells and grouped into hydrogeologic-terrane classes according to selected ranges in median yield. Two hydrogeologic terranes (gneiss-granite and schist-sandstone) were classified in the Blue Ridge Physiographic Province, and three hydrogeologic terranes (phyllite-gabbro, gneiss-schist, and shale-sandstone) in the Piedmont Physiographic Province. The names of the hydrogeologic terranes correspond to the two rock types that compose the most area within the terrane. The classes of median well yield for the Blue Ridge Physiographic Province were less than or equal to 24 gal/min (gneissmetamorphic and igneous rocks of the Blue Ridge and Piedmont Physiographic Provinces and granite) and greater than 24 gal/min (schist-sandstone). The classes of median well yield for the constitute less than 10 percent of the study area. Carbonate rocks underlie the Conestoga Valley section Piedmont Physiographic Province were less than or equal to 12 gal/min (phyllite-gabbro), greater than of the Piedmont in southeastern Pennsylvania, the Frederick Valley in central Maryland, and small 12 to 40 gal/min (gneiss-schist), and greater than 40 gal/min (shale-sandstone). An analysis of variance valleys and coves in the Blue Ridge Physiographic Province in Tennessee and in the Piedmont in performed at a probability (alpha level) of 0.05 indicated that the median yield for any one Alabama (fig. 1). Although poorly represented in the study data base, the limestone, dolomite, and hydrogeologic terrane differs significantly from the median yield of every other terrane within the same marble in these valleys produce as much as 1,800 gal/min to large-diameter municipal and industrial physiographic province. The hydrogeologic terranes may be concluded to be significantly different in their water-yielding properties as indicated by the yield of wells.

> Although the median yields of the hydrogeologic terranes are significantly different, the data sets for the terranes overlap to such a degree (fig. 4) that the variation in yield within a terrane may be more important than the median or central tendency. One measure of the variation is the interquartile range, or middle 50 percent range (25th to 75th percentile). In the Blue Ridge Physiographic Province, the interquartile range of the schist-sandstone hydrogeologic terrane overlaps the interquartile range of the gneiss-granite hydrogeologic terrane by as much as 80 percent (fig. 4), making questionable the value of seeking a water supply from one hydrogeologic terrane versus another when only a few wells are to be used. The overlap of the interquartile ranges of adjacent classes in the Piedmont Physiographic Province is more of the order of 25 to 50 percent. The gneiss-schist hydrogeologic terrane could be divided into three hydrogeologic terranes with significantly different median yields to nondomestic wells; however, the overlap in interquartile ranges among adjacent classes would be of the order of 60

> Perhaps a more realistic estimate of well yields than the median value and an indication of their variation within hydrogeologic terranes is the interquartile range. The interquartile ranges in yields to nondomestic wells in the two hydrogeologic terranes in the Blue Ridge are 8 to 32 gal/min, gneissgranite, and 10 to 61 gal/min, schist-sandstone. The interquartile ranges in the three hydrogeologic terranes of the Piedmont Physiographic Province are 5 to 20 gal/min, phyllite-gabbro; 10 to 60 gal/min, gneiss-schist; and 35 to 220 gal/min, shale-sandstone.

Statistical characteristics of the yield values of nondomestic wells in selected rock types in each of the hydrogeologic terranes are given in table 1. In the Blue Ridge Physiographic Province, limestone in the schist-sandstone hydrogeologic terrane has nondomestic wells with the largest median (50th percentile) yield of any rock type in that province. In the Piedmont Physiographic Province, marble and shale in the shale-sandstone hydrogeologic terrane have nondomestic wells with the next to the largest median yields of any two rock types in that province. In the same hydrogeologic terrane, siltstone has nondomestic wells with the largest median yield of any rock type in the study area. Essentially all wells in siltstone are in the siliciclastic rocks in the Mesozoic basins in New Jersey.

If the quantity of data were adequate for analysis, specific capacity, in addition to well yield, could followed by a decrease in average yield with increase in average depth. Four out of seven areas may be be used to classify and map hydrogeologic terranes. Unfortunately, the distribution of specific-capacity concluded to have average well yields that are substantially greater for wells completed between 400 measurements among rock types and the small number of measurements for wells in the Blue Ridge and 600 ft below land surface compared to wells in the same areas completed between 100 and 200 ft

Physiographic Province prevented a complete analysis by rock type of these data in this province. Specific-capacity data were sufficient, however, to at least evaluate the classification of hydrogeologic terranes based on well yield. To perform this evaluation, the authors assigned specific-capacity values grouped by rock types to the same rock types and hydrogeologic terranes as used in the analysis of well yields (fig. 5). The ranking of median values of specific capacity is the same as for well yield. Generally, the grouping of rock types into terranes using median values of specific capacity would be similar to groupings using values of well yield. An analysis of variance performed at a probability relating the rock type within each hydrogeologic terrane within each province back to the mapped (alpha level) of 0.05 indicated that the median specific-capacity value for any one hydrogeologic geologic units with the corresponding rock type. The yields of nondomestic wells were obtained from terrane differs significantly from the median specific capacity for every other terrane within the same the GWSI database of the USGS in each State. The analysis of maps and well records in order to physiographic province. The hydrogeologic terranes may be concluded to be significantly different in

> Statistical characteristics of the specific-capacity values of nondomestic wells in selected rock types in each of the hydrogeologic terranes of the Piedmont Physiographic Province are given in table 2. A comparison of the value of the median specific capacity for a selected rock type with the median values for other rock types in the same hydrogeologic terrane reveals how well the selected rock type (assigned to the hydrogeologic terranes by yield) fits into its hydrogeologic terrane. In regard to the median (50th percentile) specific capacity, the following rock types would appear to be poor fits within their respective hydrogeologic terranes: tuff and granite in the gneiss-schist hydrogeologic terrane have median values that would fit more appropriately in the phyllite-gabbro terrane; limestone and conglomerate in the gneiss-schist hydrogeologic terrane have median values that would fit more appropriately in the shale-sandstone hydrogeologic terrane. Tuff can be dismissed because of the small sample size. The remaining misfits suggest the possibility of a different classification based on specific capacity alone. However, the classification of hydrogeologic terranes based on well yield has significant differences among terranes and is a useful hydrologic subdivision of the Blue Ridge and Piedmont Physiographic Provinces.

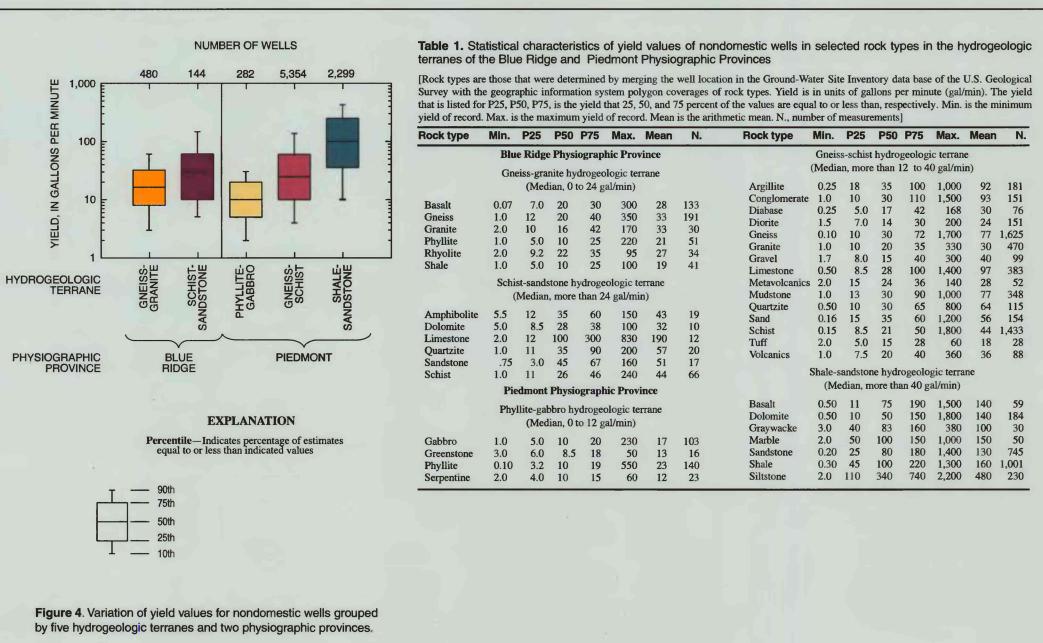
HYDROGEOLOGIC TERRANE MAP

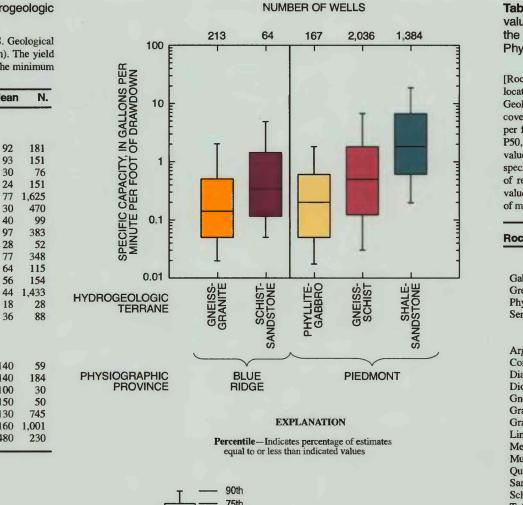
Hydrogeologic terranes were mapped by assigning rock types in the coverage of rock types to the appropriate hydrogeologic terrane that was based on well yield. This hydrogeologic terrane coverage was then combined with a base map having the same coordinate system to produce the hydrogeologic terrane map (fig. 6). The hydrogeologic terranes coincide with the outcrop areas of the geologic units with the corresponding rock types. The map unit "hydrogeologic terrane not defined" contains two general categories of rocks. The more abundantly populated category contains rock types for which there were fewer than 10 measurements of well yield, and the rock type could not be assigned to a hydrogeologic terrane. The less abundantly populated category contains rock types for which no single rock-type term 33° could be applied because of the varied lithologic composition of the original geologic unit.

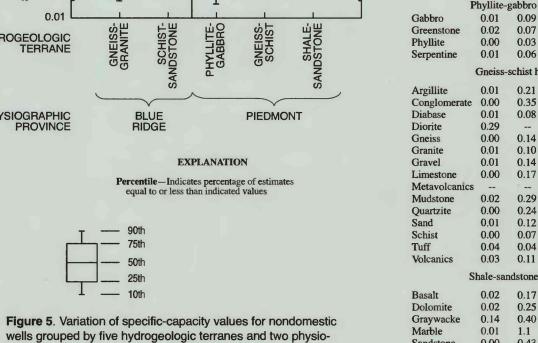
The schist-sandstone hydrogeologic terrane in the Blue Ridge Physiographic Province has the largest median well yields in that province and is predominantly schist, sandstone, and quartzite at the range in yields of water to wells completed in any particular rock type can span several orders of southwestern end and along the northwestern edge of the province. The shale-sandstone hydrogeologic magnitude and overlap the ranges of well yields in other rock types. Any analysis of this variation terrane in the Piedmont Physiographic Province has the largest median well yields and is predominantly requires a large amount of well data to describe differences in the yield of water to wells within each shale, sandstone, and siltstone in the three northeasternmost Mesozoic basins in the study area in Maryland, New Jersey, Pennsylvania, and Virginia.

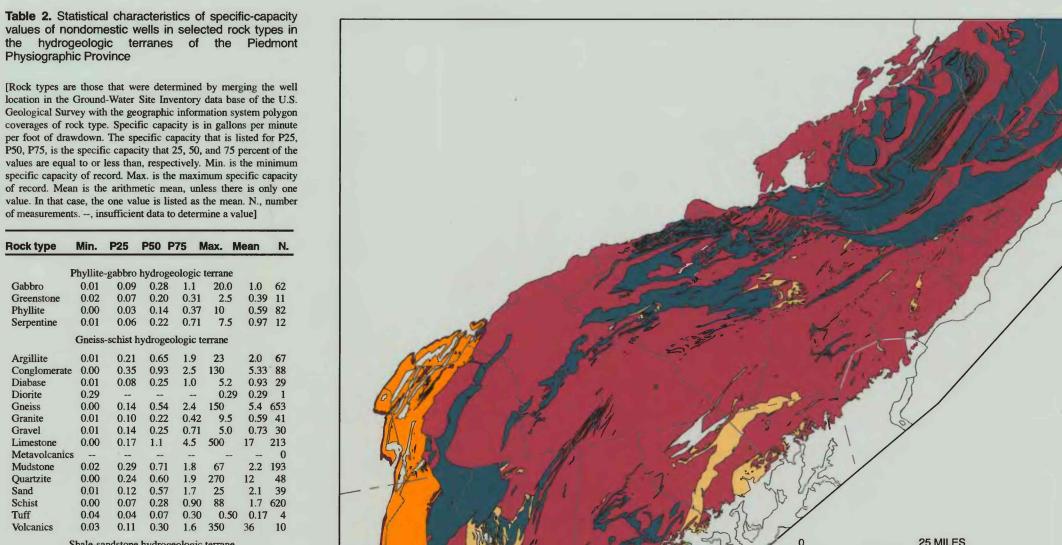
Base from U.S. Geological Survey

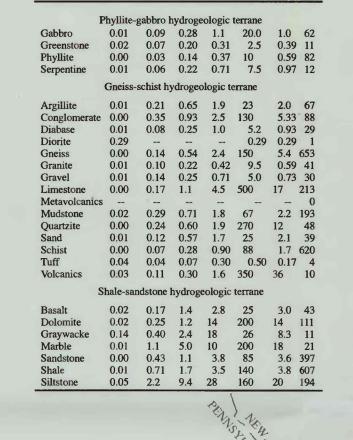
DLG data, 1:100,000

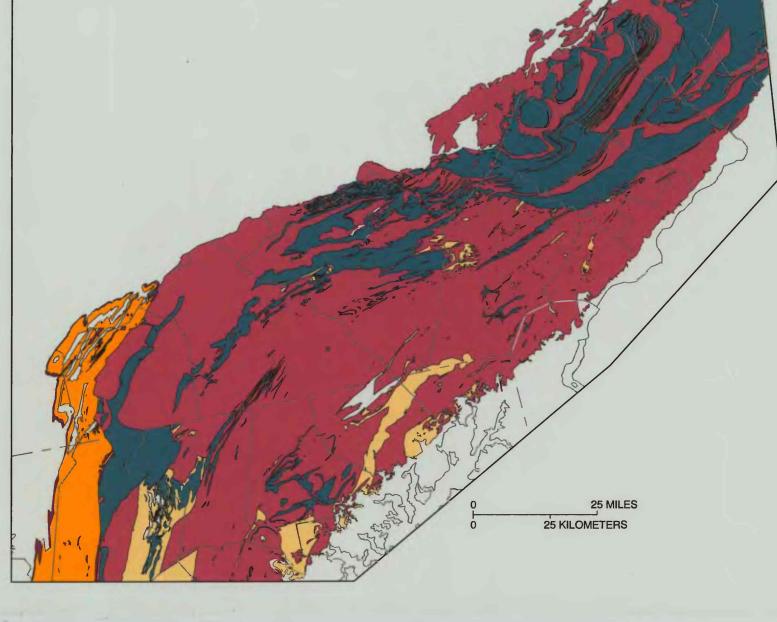


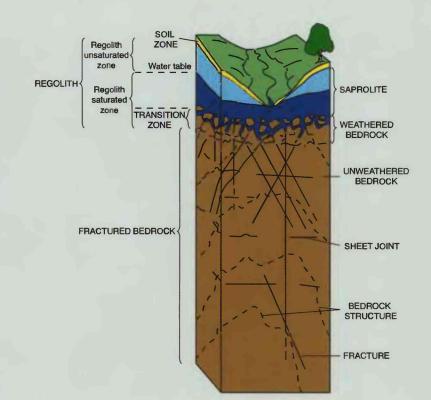


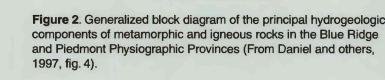


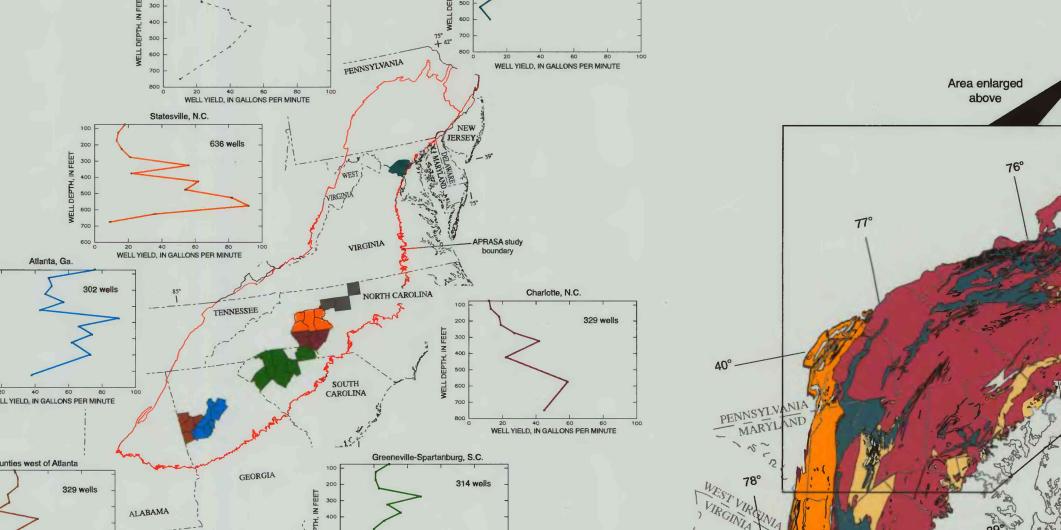




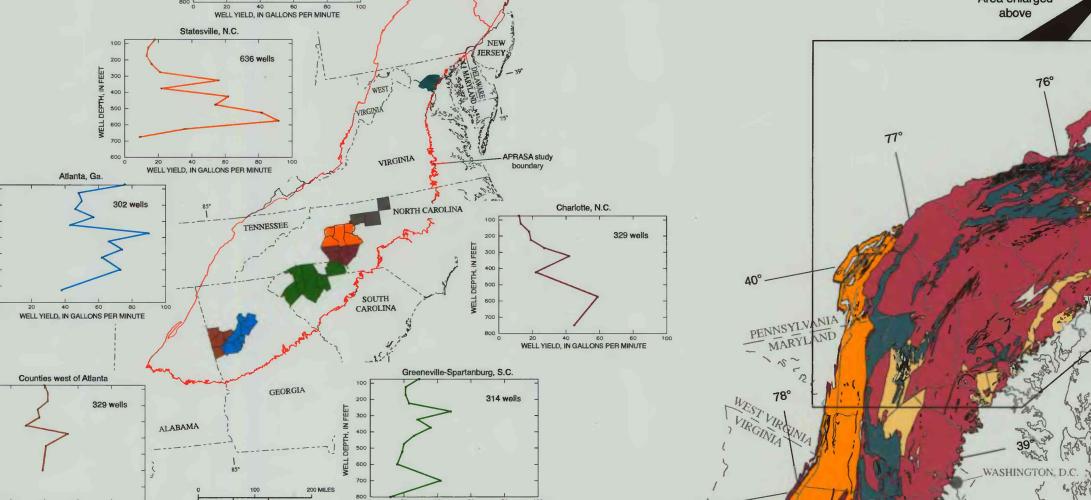


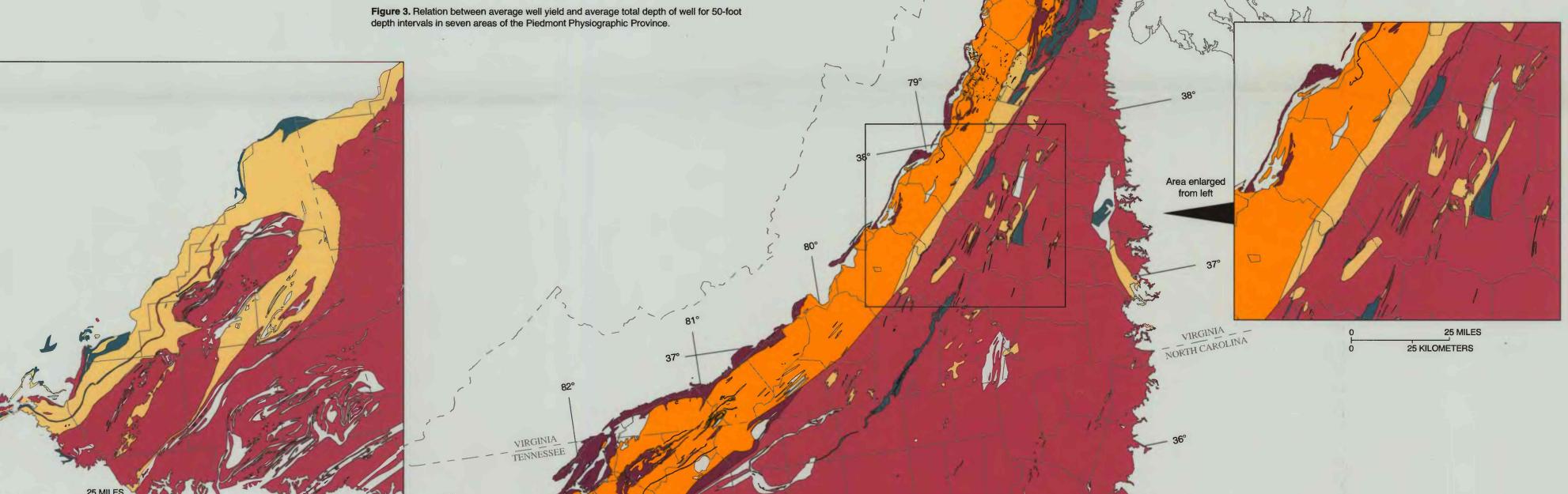


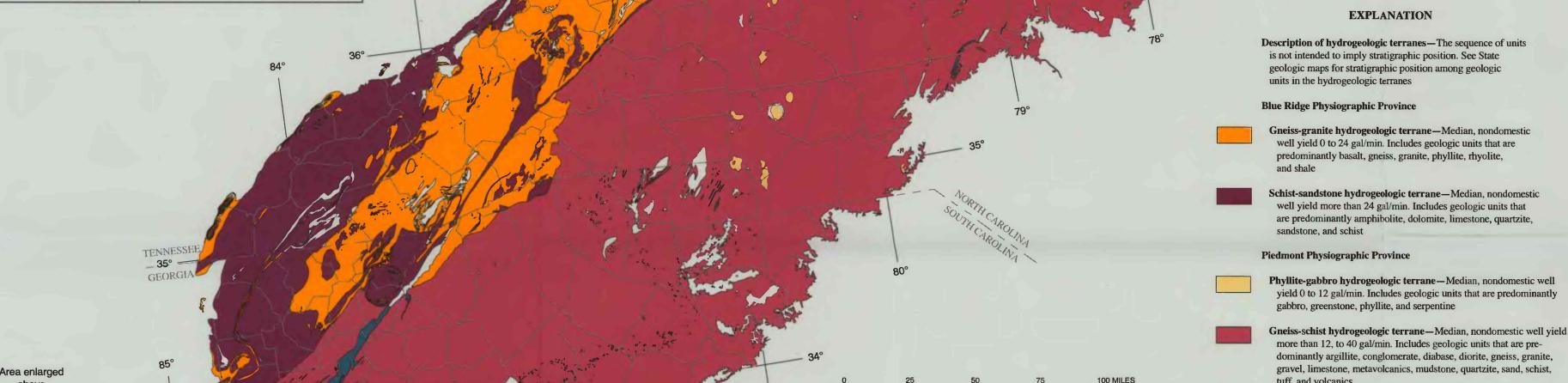


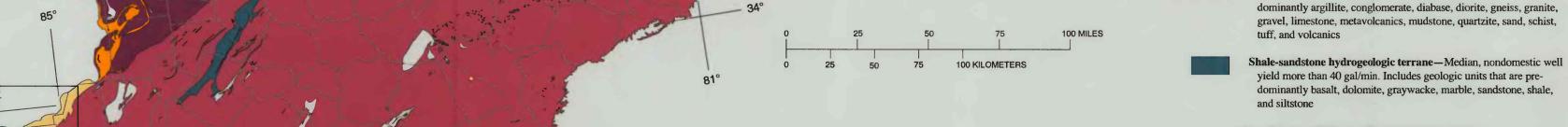


graphic provinces.









HYDROGEOLOGY AND HYDROGEOLOGIC TERRANES OF THE BLUE RIDGE AND

PIEDMONT PHYSIOGRAPHIC PROVINCES IN THE EASTERN UNITED STATES

T.O. Mesko, L.A. Swain, and E.F. Hollyday

Figure 6. Location of the hydrogeologic terranes of the Blue Ridge and

Piedmont Physiographic Provinces in the Eastern United States.

Blue Ridge and Piedmont Physiographic Provinces Hydrogeologic terrane not defined—Includes geologic units whose

rock type had fewer than 10 samples of well yield or whose lithologic composition was too varied to assign a rock type

EXPLANATION

SUMMARY

Severe and prolonged droughts between 1961 and 1988, combined with increased demands for freshwater supplies in the United States, have resulted in a critical need to assess the potential for development of ground- and surface-water supplies. The purpose of this atlas is to assess ground-water supplies in the Blue Ridge and Piedmont Physiographic Provinces within the APRASA study area.

The Blue Ridge and Piedmont Physiographic Provinces are underlain by metamorphic, igneous, and sedimentary rocks, among which gneiss, schist, granite, and phyllite underlie more than 64 percent of each province. The rocks were subjected to uplift during the Cenozoic Era, and subsequent weathering and erosion opened or widened existing fractures or created new ones by stress relief. The water-storage and transmission characteristics of the bedrock and the regolith and the hydraulic connection between the bedrock and the regolith determine the water-supply potential of the aquifers in the metamorphic and igneous rocks in the two provinces. Because of the relatively large porosity of the regolith, recharge is stored primarily in the regolith and is released slowly to underlying bedrock fractures. Because fractures in the bedrock act as conduits for ground-water flow, well yields are greatest where wells intersect fractures that are large, numerous, or both. An analysis of records of wells in seven areas of the Piedmont indicated that four areas may have average well yields that are substantially greater for wells completed between 400 and 600 feet below land surface compared to wells completed between 100 and 200 feet.

Several basins and valleys that are filled with sedimentary rocks lie within the metamorphic and igneous rocks of the Blue Ridge and Piedmont Physiographic Provinces and constitute about 10 percent of the study area. Limestone, dolomite, and marble in these valleys produce as much as 1,800 gal/min to large-diameter municipal and industrial wells from conduits dissolved in the dense rock. Siltstone, red shale, sandstone, conglomerate, and diabase fill a series of 15 elongated, down-faulted basins that lie within the Piedmont in a discontinuous belt extending from New York City into South Carolina. The three Mesozoic basins near the northeastern end of the belt contain fractured shale, siltstone, and sandstone, which yield as much as 2,200 gal/min to individual wells.

Hydrogeologic terranes were classified separately within the two physiographic provinces by relating rock type, as described in State geologic maps, to U.S. Geological Survey GWSI records of yield of nondomestic wells in the Blue Ridge and Piedmont Physiographic Provinces. State geologic maps were scanned, edited, and annotated to produce line and polygon coverages of the mapped occurrence of each geologic unit in the study area. Geologic units with the same rock type were merged to create a coverage of 35 rock types in the Blue Ridge and 53 rock types in the Piedmont Physiographic Provinces. Records of 40,315 wells in the APRASA part of the Blue Ridge and Piedmont Physiographic Provinces were retrieved from the GWSI files of the USGS. Among these, the wells used in the statistical analysis were 8,559 nondomestic wells with values of yield and 3,864 nondomestic wells with values of specific capacity.

Values of yield were retrieved from each well record, grouped by province and rock type, and analyzed to derive statistical characteristics of yield for each of 38 combinations of province and rock type. For each physiographic province, the rock types were then ranked in order of increasing median yield and grouped into two or more hydrogeologic terranes according to selected ranges in median yield. The interquartile ranges in yields to nondomestic wells in the two hydrogeologic terranes in the Blue Ridge Physiographic Province are 8 to 32 gal/min, gneiss-granite, and 10 to 61 gal/min, schistsandstone. The interquartile ranges in the three hydrogeologic terranes of the Piedmont Physiographic Province are 5 to 20 gal/min, phyllite-gabbro; 10 to 60 gal/min, gneiss-schist, and 35 to 220 gal/min, shale-sandstone. An analysis of variance indicated that the hydrogeologic terranes are significantly different in their water-yielding properties. In the shale-sandstone hydrogeologic terrane of the Piedmont Physiographic Province, siltstone in the Mesozoic basins of New Jersey has wells with the largest median yield of any rock type in the study area. In the schist-sandstone hydrogeologic terrane of the Blue Ridge Physiographic Province, limestone has nondomestic wells with the largest median yield of any rock type in this province. An evaluation of the classification of hydrogeologic terranes based on yield using specific-capacity data indicated that the ranking of median values of specific capacity is the same as for well yield. The classification of hydrogeologic terranes based on well yield has significant differences among terranes and is a useful hydrologic subdivision of the Blue Ridge and Piedmont

Hydrogeologic terranes were mapped by assigning rock types in the coverage of rock types to the appropriate hydrogeologic terrane that was based on well yield. The shale-sandstone hydrogeologic terrane in the Piedmont Physiographic Province has the largest median well yields and is predominantly shale, sandstone, and siltstone in the Mesozoic basins in Maryland, New Jersey, Pennsylvania, and

REFERENCES CITED

Berg, T.M., Edmunds, W.E., Geyer, A.R., and others, comps., 1980, Geologic map of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 1, 3 sheets, scale 1:250,000. Brown, P.M., and Parker, J.M., III, 1985, Geologic map of North Carolina: Raleigh, N.C., The North Carolina Geological Survey, 1 sheet, scale 1:500,000. Calver, J.L., and Hobbs, C.R.B., eds., 1963, Geologic map of Virginia: Virginia Division of Mineral Resources map. 1 sheet, scale 1:500,000.

Cardwell, D.H., Erwin, R.B., and Woodward, H.P., comps., 1968, Geologic map of West Virginia: West Virginia Geological and Economic Survey map, 2 sheets, scale 1:250,000. Cleaves, E.T., Edwards, Jonathan, Jr., and Glaser, J.D., comps., 1968, Geologic map of Maryland: Maryland Geological Survey map, 1 sheet, scale 1:250,000. Daniel, C.C., III, 1989, Statistical analysis relating well yield to construction practices and siting of wells in

the Piedmont and Blue Ridge provinces of North Carolina: U.S. Geological Survey Water-Supply Paper Daniel, C.C., III, and Payne, R.A., 1990, Hydrogeologic unit map of the Piedmont and Blue Ridge Provinces of North Carolina: U.S. Geological Survey Water-Resources Investigations Report 90-4035, 1 sheet, scale 1:500.000

Daniel, C.C., III, Smith, D.G., and Eimers, J.L., 1997, Hydrogeology and simulation of ground-water flow in the thick regolith-fractured crystalline rock aquifer system of Indian Creek Basin, North Carolina: U.S. Geological Survey Water-Supply Paper 2341-C, 137 p. Hardeman, W.D., 1966, Geologic map of Tennessee: Tennessee Division of Geology map, 4 sheets,

Heath, R.C., 1984, Ground-water regions of the United States: U.S. Geological Survey Water-Supply Paper Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Amsterdam, New York, Elsevier, 522 p. Hollyday, E.F., and Hileman, G.E., 1996, Hydrogeologic terranes and potential yield of water to wells in the Valley and Ridge Physiographic Province in the Eastern and Southeastern United States: U.S. Geological Survey Professional Paper 1422-C, 30 p.

Hollyday, E.F., Hileman, G.E., and Duke, J.E., 1997, The Elkton aquifer or western toe aquifer of the Blue Ridge Mountains—a regional perspective, in Younos, Tamim, Burbey, T.J., Kastning, E.H., and Poff, J.A., eds., Karst-Water Environment Symposium, Roanoke, Va., 1997, Proceedings: Blacksburg, Va., Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, p. 71-79. Knopman, D.S., 1990, Factors related to the water-yielding potential of rocks in the Piedmont and Valley and Ridge Provinces of Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 90-4174, 52 p.

Lawton, D.E., and others, 1976, Geologic map of Georgia: Georgia Geological Survey map, 1 sheet, scale 1:500,000. Lewis, J.V., and Kummel, H.B., 1912, Geologic map of New Jersey: New Jersey Department of Conservation and Economic Development Atlas Sheet 40, 1 sheet, scale 1:250,000. Revised by

Johnson, M.E., 1950. Mesko, T.O., 1993, Delineation of hydrogeologic terranes in the Piedmont and Blue Ridge Physiographic Provinces—Southeastern and Mid-Atlantic United States [abs.]: American Association of Petroleum Geologists Bulletin, v. 77, no. 8, p. 1471. Nutter, L.J., and Otton, E.G., 1969, Ground-water occurrence in the Maryland Piedmont: Maryland

Geological Survey Report of Investigations 10, 56 p. Osborne, W.E., Szabo, M.W., Copeland, C.W., Jr., and Neathery, T.L., 1989, Geologic map of Alabama: Geological Survey of Alabama Special Map 221, 1 sheet, scale 1:500,000. Overstreet, W.C., and Bell, Henry, III, 1965, Geologic map of the crystalline rocks of South Carolina: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-413, 1 sheet, scale 1:250,000. Stewart, J.W., 1962, Water-yielding potential of weathered crystalline rocks at the Georgia Nuclear Laboratory: U.S. Geological Survey Professional Paper 450-B, p. B106 - B107.

Swain, L.A., Hollyday, E.F., Daniel, C.C., III, and Zapecza, O.S., 1991, Plan of study for the regional aquifer-system analysis of the Appalachian Valley and Ridge, Piedmont, and Blue Ridge Physiographic Provinces of the Eastern and Southeastern United States, with a description of study area geology and hydrogeology: U.S. Geological Survey Water-Resources Investigations Report 91-4066, 44 p. Survey Geologic Map Series, no. 3, scale 1:24,000.

Woodruff, K.D., and Thompson, A.M., 1972, Geology of the Newark area, Delaware: Delaware Geological _____ 1975, Geology of the Wilmington area, Delaware: Delaware Geological Survey Geologic Map Series, no. 4, scale 1:24,000.

CONVERSION FACTORS AND VERTICAL DATUM		
Multiply	Ву	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi ²)	2.590	square kilometer
gallon per minute (gal/min)	0.06308	liter per second
feet per day (ft/d)	0.305	meter per day

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of

INTERIOR-GEOLOGICAL SURVEY, RESTON, VIRGINIA-2000

below land surface.